7.2 Describing Fields

In Figure 7.5 (A), a woodcutter exerts a splitting force on a log by direct contact between the axe and the log. In contrast, in Figure 7.5 (B), a charged comb is exerting a force on charged pith balls without coming into contact with the balls. This electrostatic force between the comb and pith balls is an example of an action-at-a-distance force. You have just been studying the characteristics of the three common action-at-a-distance forces: gravitational, electric, and magnetic forces. The phrase **action at a distance** describes some of the characteristics of these forces, but does not really explain how these results are achieved. The critical question now is: How is each mass or charge or magnet "aware" of the other?

Figure 7.5 **(A)** A woodcutter chopping a log is an example of a contact force. **(B)** When a charged comb exerts a force on charged pith balls, the force is acting at a distance and is a non-contact force.

The question of how an object can exert a force on another object without making contact with the object was addressed by Michael Faraday (1792–1867), who proposed the concept of a field. This field concept became quite popular and was extended to explain the gravitational forces between masses.

The fundamental concept is that a **field** is a property of space. An object influences the space around it, setting up either an electric, gravitational, or magnetic field. The object producing the field is called the "source" of the field. This field in turn exerts a force on other objects located within it. This concept is consistent with the inverse square law, which implies that an object influences the space around it.

SECTION EXPECTATIONS

- Define and describe the concepts related to electric, gravitational, and magnetic fields.
- Compare the properties of electric, gravitational, and magnetic fields.
- Analyze the electric field and the electric forces produced by point charges.
- Sketch simple field patterns using field lines.

KEY TERMS

- action at a distance
- field
- test charge
- electric field intensity
- electric field
- gravitational field intensity
- magnetic field intensity
- electric field line
- gravitational field line
- magnetic field line

HISTORY LINK
In 1600, William Gilbert (1540–1603) hypothesized that the rubbing of certain materials, such as amber, removes a fluid or "humour" from the material and releases an "effluvium" into the surroundings. He proposed that the effluvium made contact with other materials and caused the force now known as the "electrostatic force." As you continue to study this section, decide whether Gilbert was on the right track.

Defining Field Intensity

Figure 7.6 illustrates the generation of an electric field by a charge, q_1. The density of the shading designates the strength of the field. If a second charge, q_2, is introduced into the field at point P, for example, it is the *field* that interacts with q_2. Because this is a local interaction, it is not necessary to explain how forces can act between objects separated by any distance.

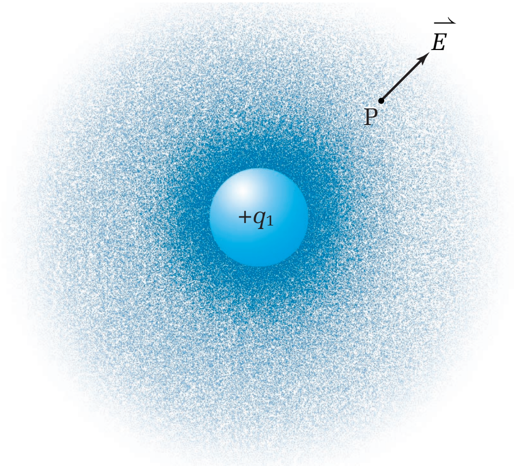

Figure 7.6 Charge q_1 influences the space around it by generating an electric field. The density of the shading indicates the strength of the field.

To describe the field around a charge, q, it is convenient to use the concept of a test charge. By definition, a **test charge** is a point charge with a magnitude so much smaller than the source charge that any field generated by the test charge itself is negligible in relation to the field generated by the source charge. You can place the test charge, q_t, at any point within the field generated by q, and then take the following steps.

- Write Coulomb's law to describe the force between the source charge, q, and the test charge, q_t. $$F = k\frac{qq_t}{r^2}$$
- Divide both sides of the equation by q_t. $$\frac{F}{q_t} = k\frac{q}{r^2}$$

The term on the right-hand side of the equation contains only the source charge and the distance that q_t is from the source charge. Since it is independent of anything that might be located at q_t, it provides a convenient way to describe the condition of space at q_t. Now the term on the left-hand side of this equation is defined as the magnitude of the **electric field intensity**, $\vec{E}$, which is commonly called the **electric field**.

DEFINITION OF ELECTRIC FIELD INTENSITY

The electric field intensity at a point is the quotient of the electric force on a charge and the magnitude of the charge located at the point.

$$\vec{E} = \frac{\vec{F}_Q}{q}$$

Quantity	Symbol	SI unit
electric field intensity	$\vec{E}$	$\frac{N}{C}$ (newtons per coulomb)
electric force	$\vec{F}_Q$	N (newtons)
electric charge	q	C (coulombs)

Unit Analysis

$$\frac{\text{newtons}}{\text{coulomb}} = \frac{N}{C}$$

Note: Electric field intensity has no unit of its own.

Since force is a vector quantity, so also is an electric field. An electric force can be attractive or repulsive, so physicists have accepted the convention that the direction of the electric field vector at any point is given by the direction of the force that would be exerted on a *positive* charge located at that point. Using this concept, you can illustrate an electric field by drawing force vectors at a variety of points in the field. As shown in Figure 7.7, the length of the vector represents the magnitude of the field at the tail of the vector, and the direction of the vector represents the direction of the field at that point.

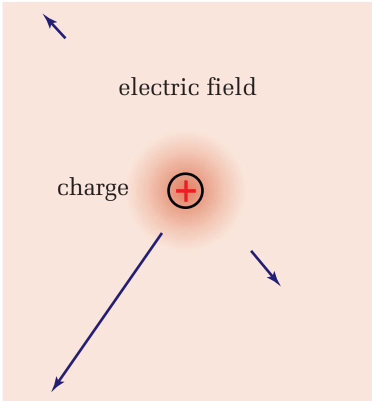

Figure 7.7 Vector arrows can be used to represent the magnitude and direction of the electric field around a charge at various locations.

SAMPLE PROBLEM

Calculating Electric Field Intensity

A positive test charge, $q_t = +2.0 \times 10^{-9}$ C, is placed in an electric field and experiences a force of $\vec{F} = 4.0 \times 10^{-9}$ N[W].

(a) What is the electric field intensity at the location of the test charge?

(b) Predict the force that would be experienced by a charge of $q = +9.0 \times 10^{-6}$ C if it replaced the test charge, q_t.

Conceptualize the Problem

- The *electric field intensity* is related to the *force* and the test *charge*.
- If you know the *electric field intensity* at a point in space, you can determine the *force* on any *charge* that is placed at that point without knowing anything about the source of the field.

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Identify the Goal

The electric field, $\vec{E}$, at a given point in space

The force, $\vec{F}$, on the new charge located at the same point

Identify the Variables

Known	Unknown
$\vec{F}_{q_t} = 4.0 \times 10^{-9}$ N[W]	$\vec{E}$
$q_t = 2.0 \times 10^{-9}$ C	$\vec{F}$
$q = 9.0 \times 10^{-6}$ C	

Develop a Strategy

Find the electric field intensity by using the equation that defines electric field.

$$\vec{E} = \frac{\vec{F}}{q_t}$$

$$\vec{E} = \frac{4.0 \times 10^{-9}\ \text{N[W]}}{2.0 \times 10^{-9}\ \text{C}}$$

$$\vec{E} = 2.0\ \frac{\text{N}}{\text{C}}\text{[W]}$$

(a) The electric field intensity is $\vec{E} = 2.0\ \frac{\text{N}}{\text{C}}\text{[W]}$.

Rearrange the equation for electric field to solve for the new force.

$$\vec{E} = \frac{\vec{F}}{q}$$

$$\vec{F} = q\vec{E}$$

Substitute the numerical values and solve.

$$\vec{F} = (9.0 \times 10^{-6}\ \text{C})\left(2.0\ \frac{\text{N}}{\text{C}}\text{[W]}\right)$$

$$\vec{F} = 18 \times 10^{-6}\ \text{N[W]}$$

$$\vec{F} = 1.8 \times 10^{-5}\ \text{N[W]}$$

(b) The force on the 9.0×10^{-6} C charge is $\vec{F} = 1.8 \times 10^{-5}$ N[W].

Validate the Solution

You would expect the electric field to have units N/C and be pointing west. The magnitude of the field seems to be reasonable in relation to the charge and force.

Since the second charge is larger than the first, you would expect the second force to be larger than the first. Charges in the microcoulomb range are considered to be average charges that occur in electrostatic experiments.

PRACTICE PROBLEMS

11. A positive charge of 3.2×10^{-5} C experiences a force of 4.8 N to the right when placed in an electric field. What is the magnitude and direction of the electric field at the location of the charge?

12. An electric field points due east with a magnitude of 3.80×10^{3} N/C at a particular location. If a charge of $-5.0\ \mu$C is placed at this location, what will be the magnitude and the direction of the electric force that it experiences?

13. A negative charge of 2.8×10^{-6} C experiences an electrostatic force of 0.070 N to the right. What is the magnitude and direction of the electric field at the location of the charge?

14. A small charged sphere is placed at a point in an electric field that points due west and has a magnitude of 1.60×10^4 N/C. If the sphere experiences an electrostatic force of 6.4 N east, what is the magnitude and sign of its charge?

A discussion similar to that for the electric field intensity can be made for gravitational field intensity. A mass, such as Earth, can exert a gravitational force on a test mass placed in its vicinity. The ratio of the gravitational force to the test mass depends only on the source and the location in the field. This ratio is called the **gravitational field intensity**, for which the symbol is $\vec{g}$.

DEFINITION OF GRAVITATIONAL FIELD INTENSITY

The gravitational field intensity at a point is the quotient of the gravitational force and the magnitude of the test mass.

$$\vec{g} = \frac{\vec{F}_g}{m}$$

Quantity	Symbol	SI unit
gravitational field intensity	$\vec{g}$	$\frac{N}{kg}$ (newtons per kilogram)
gravitational force	$\vec{F}_g$	N (newtons)
mass	m	kg (kilograms)

Unit Analysis

$$\frac{\text{newtons}}{\text{kilogram}} = \frac{N}{kg}$$

In the past, you have used the symbol g to represent the acceleration due to gravity at Earth's surface. If you analyze the equation that described gravitational field intensity in the box above, you will see that it can be rearranged to give $\vec{F} = m\vec{g}$, which is the same as the equation for the weight of an object at Earth's surface. So, in fact, the g that you have been using is the same as the gravitational field intensity at Earth's surface.

Conceptual Problem

- Show that the units for g, m/s^2, are equivalent to the units for gravitational field intensity, or N/kg.

SAMPLE PROBLEM

Calculating Gravitational Field Intensity

A mass of 4.60 kg is placed 6.37×10^6 m from the centre of a planet and experiences a gravitational force of attraction of 45.1 N.

(a) Calculate the gravitational field intensity at this location.

(b) Discuss the significance of your answer.

Conceptualize the Problem

- The definition of *gravitational field intensity* is the gravitational *force* per unit *mass*.

Identify the Goal

The gravitational field intensity, $\vec{g}$, at this location

Identify the Variables

Known	Unknown
$\lvert\vec{F}\rvert = 45.1$ N	$\vec{g}$
$m = 4.60$ kg	
$r = 6.37 \times 10^6$ m	

Develop a Strategy

Find the gravitational field intensity by using the equation for field intensity and the given variables.

$$\vec{g} = \frac{\vec{F}}{m}$$

$$\lvert\vec{g}\rvert = \frac{45.1\ \text{N}}{4.60\ \text{kg}}$$

$$\vec{g} = 9.80\ \frac{\text{N}}{\text{kg}}\text{[in the direction of the force]}$$

(a) The gravitational field intensity at this location is 9.80 N/kg.

Look for recognizable characteristics, then investigate other data.

The value of the field intensity is identical to that of Earth's near its surface.

The distance given is actually the average radius of Earth.

(b) The location seems to be at the surface of Earth, although another alternative is that it could be *above* the surface of a planet with gravitational field intensity at its surface that is greater than that of Earth.

Validate the Solution

The units are correct for gravitational field. The values for both distance and field intensity provide more validation, because they are identical to the values for the surface of Earth. However, this does not preclude the possibility of the object being above another planet.

PRACTICE PROBLEMS

15. What is the gravitational field intensity at the surface of Mars if a 2.0 kg object experiences a gravitational force of 7.5 N?

16. The gravitational field intensity on the surface of Jupiter is 26 N/kg. What gravitational force would a 2.0 kg object experience on Jupiter?

17. The planet Saturn has a gravitational field intensity at its surface of 10.4 N/kg. What is the mass of an object that weighs 36.0 N on the surface of Saturn?

18. What would be the gravitational field intensity at a location exactly one Saturn radius above the surface of Saturn?

19. What is the centripetal acceleration of a satellite orbiting Saturn at the location described in the previous problem?

The gravitational field can also be mapped in the region of a source mass by drawing the gravitational field vectors at corresponding points in the field. Similar to the electric field, the vector length represents the magnitude of the gravitational field and the direction of the vector represents the direction in which a gravitational force would be exerted on a test mass placed in the field.

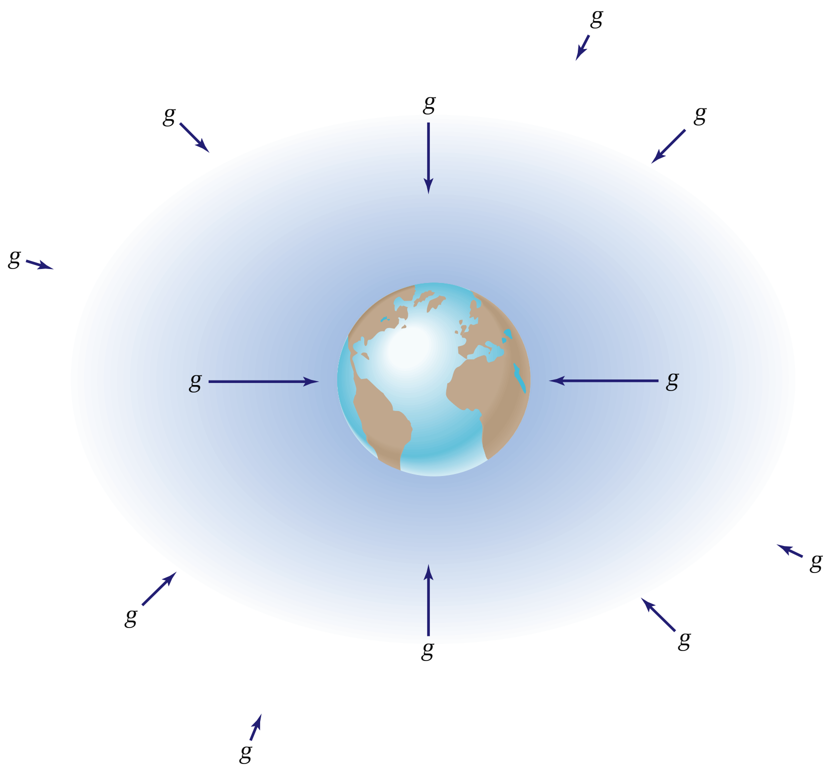

Figure 7.8 Earth's gravitational field can be represented by vectors, with the length of each being proportional to the field intensity at that point.